PAN-PACIFIC ENTOMOLOGIST
69(3): 221–235, (1993)

# BIOLOGICAL STUDIES OF *HEMICOELUS GIBBICOLLIS* (LECONTE) (COLEOPTERA: ANOBIIDAE), A SERIOUS STRUCTURAL PEST ALONG THE PACIFIC COAST: LARVAL AND PUPAL STAGES

Daniel A. Suomi and Roger D. Akre
Department of Entomology, Washington State University,
Pullman, Washington 99164

*Abstract.*—*Hemicoelus gibbicollis* (LeConte) is an important structure-infesting anobiid beetle found along the coastal areas of western North America. Little had been known about this insect because the larvae escaped detection while feeding within building timbers. Radiography was used to document the development of larvae over a 2 year period. Larvae move about 1 cm each month and may spend up to 6 years feeding on wood. Wood moisture between 13 and 19% is the key element contributing to successful colonization of timbers. Symbiotic yeasts present in larval mycetomes probably aid in nutrition. No correlation was found between the number of adult exit holes and live larvae present in wood blocks.

*Key Words.*—Insecta, *Hemicoelus gibbicollis,* structure-infesting, larva, pupa, symbiont

Throughout many areas of the world, structure-infesting beetles in the family Anobiidae are serious pests (Hickin 1981). Larvae live within wooden timbers, producing extensive feeding galleries that result in a weakened structure. The cost of wood replacement and/or chemical control can be quite high. Despite the damage they cause, little is known about most species because of a long life cycle and difficulty in rearing.

Along coastal areas of western North America, *Hemicoelus gibbicollis* (LeConte) is the most damaging anobiid. This species occurs in >90% of infested structures in western Washington State (Suomi 1992). Although considered to be the most destructive anobiid in Washington, Oregon, California, and British Columbia (Doane et al. 1936, Linsley 1943, CIPR 1988), its biology was unrecorded. Recent estimates show the beetle is responsible for $7–8 million in wood replacement and chemical control costs annually in Washington (Suomi 1992).

Documenting the behavior of insects residing in wood is exceedingly difficult because the life stage under study is hidden from view and can be damaged if attempts are made to remove it for examination. Additionally, many wood-inhabiting insects have long life cycles, often 4–6 years or more, and do not readily lend themselves to laboratory study. Radiographic devices allow these insects to be observed without interference in their activities (Parkin 1940, Bletchly 1961, Villani & Wright 1988) and are a necessary tool for studying their habits. This, and a previous paper (Suomi & Akre 1993), describe the biology and habits of *H. gibbicollis.*

## MATERIALS AND METHODS

*Wood Collection.*—Subflooring, primarily Douglas-fir, *Pseudotsuga menziesii* (Mirbel), infested with *H. gibbicollis* larvae was collected from western Washington

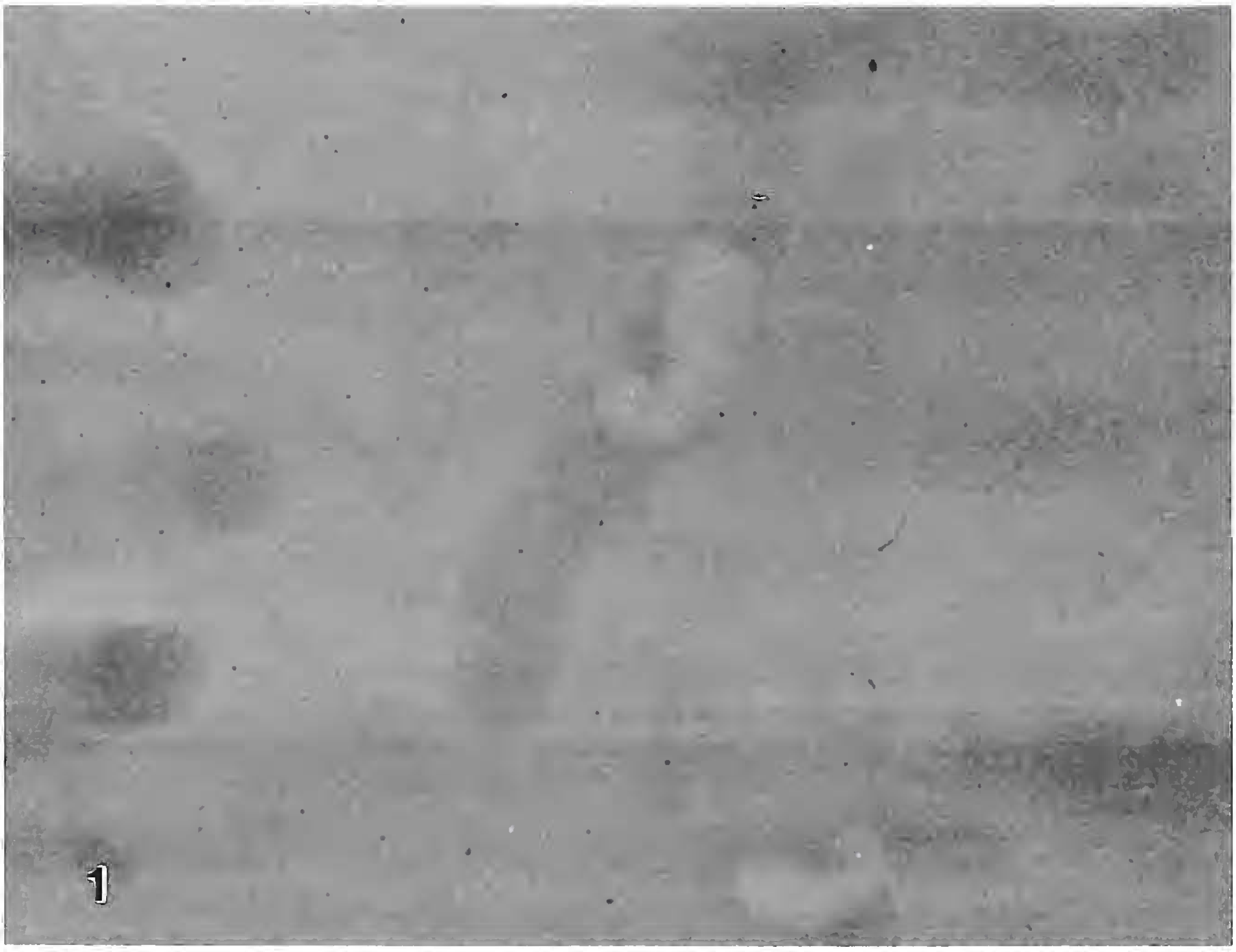

Figure 1. Radiograph of *H. gibbicollis* larvae within a structural timber.

and Oregon homes and outbuildings during June, July, and August, 1987–1991. This material was transported to the laboratory at Washington State University in sealed containers to maintain wood moisture at the higher levels found in coastal areas.

*Radiography.*—Wood blocks (9 cm by 9 cm by 2 cm) were cut from infested timbers and x-rayed monthly at 35 kV for 75 sec using a Faxitron Radiographic Inspection System Model 43804 (Hewlett-Packard, McMinnville, Oregon). This unit has a beryllium window which transmits "soft" radiation that is relatively harmless to biological tissues. Radiographic film (Kodak Radiographic Film, Min-R, Eastman Kodak, Rochester, New York) was exposed at room temperature, immersed in standard x-ray developer for 5 min, rinsed in distilled water, and fixed for 5 min. Radiographs were viewed on a light table and larval positions marked (Fig. 1). A 1:1 reproduction of live larvae to images was recorded on the film. Radiographs of 20 wood blocks were taken monthly for 2 years to document larval development, movement, and survival. Measurements were made with a vernier caliper with graduations of 0.05 mm. Where appropriate, data were analyzed with MEANS Procedures (SAS Institute 1985).

*Wood Block Storage.*—Before and after radiography blocks were stored in covered, darkened boxes measuring 38 cm by 28 cm by 15 cm with 1 cm plaster of Paris/charcoal as a substrate to maintain wood moisture between 14 and 17%. Ventilation was provided through two screen covered holes (35 mm diameter) in the top cover. Wood moisture readings were taken with a Delmhorst Model RC-1C Moisture Meter (Delmhorst Instrument Company, Boonton, New Jersey). An environmental chamber was used to maintain conditions at 65 ± 3% RH and 18 ± 1° C as commonly found in crawl spaces under buildings in western Washington.

Additional wood blocks were stored in a separate environmental chamber at 15 ± 1° C and 60 ± 1% RH which kept wood moisture levels at or below 12%. During 1990–1991, a third group of blocks was transferred in bimonthly intervals from laboratory storage to an unheated garage. Daily maximum and minimum temperatures were recorded at this location (Suomi 1992: appendix 5). Sixteen other blocks were radiographed and transferred to a 1.5° C walk-in cooler for 2, 4, 6, or 8 weeks, then returned to an environmental chamber. Wood moisture was maintained at 14–15%. Additionally, 50 wood blocks were radiographed and larvae counted to assess any correlation between number of adult exit holes and total larvae present.

*First Instar Penetration Studies.*—One year old Douglas-fir dimensional lumber, locally purchased, was cut into blocks (9 cm by 9 cm by 2 cm) to clearly show the demarcation between sapwood and heartwood (Miller 1987). Thirteen blocks were sanded to produce a slightly roughened surface. A camel's hair brush was used to transfer five, newly emerged *H. gibbicollis* larvae to the sapwood: heartwood demarcation of each block. A clear, polystyrene insect diet cup (4 cm tall by 4 cm diameter) was positioned over the insects and held in place with adhesive from an electric glue gun. All blocks were stored in separate, darkened enclosures and larval penetration was recorded after 7 days.

*Larval Descriptions.*—For descriptive studies, radiographs were marked and larvae carefully extracted from within the wood. Five immatures of different sizes were dissected to extract and photograph symbiont-containing mycetomes.

## RESULTS AND DISCUSSION

*Larva.*—*Hemicoelus gibbicollis* larvae are approximately 0.6 mm long, straight, and white upon emerging from the egg (Fig. 2). There is distinct body segmentation, and small legs, with one claw, are present. A single stemma is located on each side of the hypognathus head. The mandibles are heavily sclerotized and have two apical teeth. Prodorsal asperites are present on thoracic segment III and abdominal segments 1–7. These structures most likely aid larvae in adhering to and moving through galleries within wood. As larvae develop the anterior one-third becomes slightly red-brown, and the body trunk becomes more curved (Fig. 3). This color change results from the ingestion of wood and retention of fibers within the crop. Larvae possess a hydrophobic surface layer and float in water for several minutes. This layer probably protects the immature stage from high wood moisture conditions often found in damp wood. According to Böving (1954) the larva is similar to that of *Anobium punctatum* (De Geer) except for having spiracles of a different shape and a different number of prodorsal asperites. Galleries are packed with fecal pellets that are cylindrical and tapered at each end, being somewhat "gritty" in texture when rubbed between fingers.

*Effect of X-rays on Insects.*—Radiographic techniques have been used as a nondestructive sampling method for detecting insect activity in a variety of materials (Fisher & Tasker 1940, Milner et al. 1950, Dennis 1961, Berryman & Stark 1962, Villani & Wright 1988). X-rays have little effect on biological tissues if low energy, long wavelengths are used and critical dosages not exceeded. Daily radiographic examinations of the granary weevil, *Sitophilus granarius* L., and rice weevil, *Sitophilus oryza* L., over a two week period produced no deleterious effects

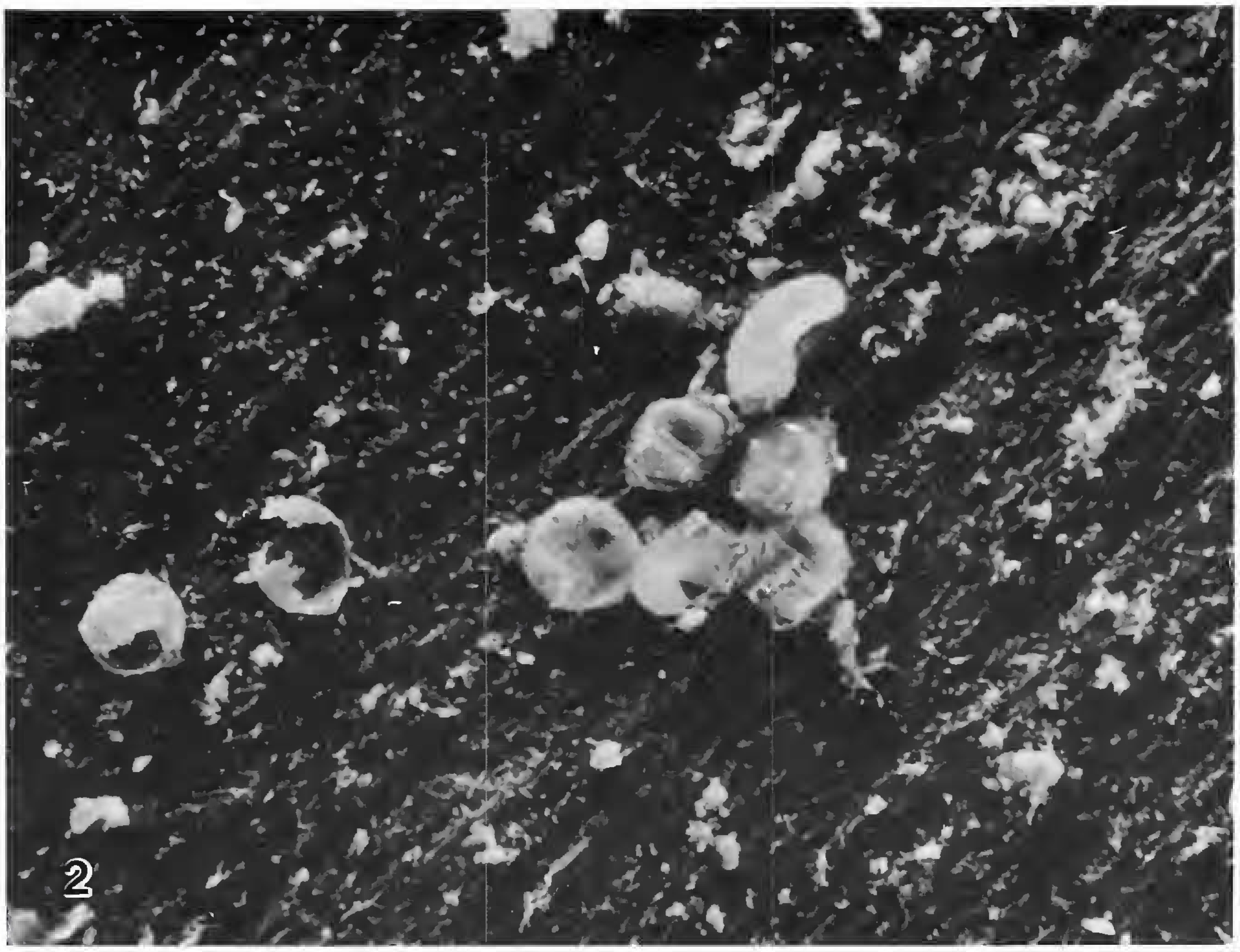

Figure 2. First instar of *H. gibbicollis*.

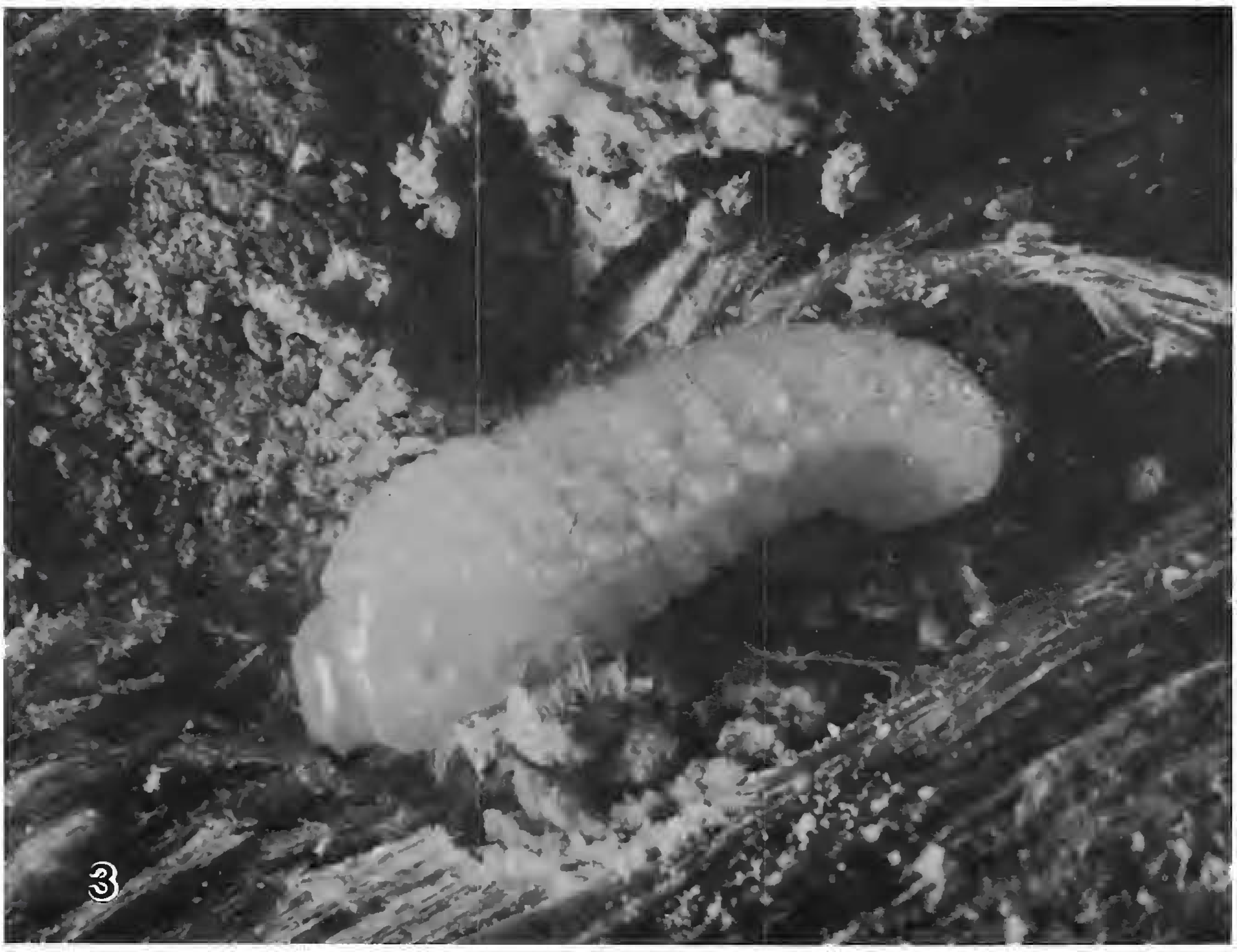

Figure 3. Mature *H. gibbicollis* larva.

on adults or larvae (Milner et al. 1950). Bletchly & Fisher (1957) and Bletchly & Baldwin (1962) used x-rays at dosages similar to those used in this study and saw no behavioral changes in *A. punctatum* larvae. According to Bletchly & Fisher (1957), over 70,000 roentgens are necessary to kill larvae of *A. punctatum*. Larvae in these studies were exposed to <1450 roentgens over 24 months. Adult *H. gibbicollis* emerging from blocks radiographed for these tests mated and produced viable offspring.

*Larval Development and Behavior.*—The number of larval instars in *H. gibbicollis* is uncertain and may vary depending on nutrition available in wood. According to Hickin (1975) the number for *A. punctatum* is not well established, but another anobiid, *Stegobium paniceum* (L.), typically has five (Hickin 1974). Böving (1954) stated that there are no major morphological changes between instars in *H. gibbicollis*. All larval sizes were often seen on radiographs of a single wood block. This most likely signifies that larvae of different generations were present although Bletchly & Farmer (1959) reported that developmental rates of *A. punctatum* differed resulting from inconsistencies of nutritional components within the same test block. Larvae were not easily observed on radiographs until they were approximately 1.5 mm long. Linscott (1971) reported that 8–18 months of development were necessary before larvae of *A. punctatum* became visible on radiographs.

Emergence time of first instars from eggs was quite variable, ranging from 27 min to over 22 h. While emerging, *H. gibbicollis* larvae consume between 25 and 75% of the chorion. Symbiotic yeasts, which are transmitted to eggs during passage through the female oviduct, are ingested by larvae in this process (Jurzitza 1979). Wood is relatively low in nutrition, particularly nitrogen (Merrill & Cowling 1966), and yeasts play a vital role in providing essential amino acids and vitamins to anobiid larvae (Pant & Fraenkel 1954, Kelsey 1958, Jurzitza 1979). These symbionts, *Symbiotaphrina* sp. (Gams & von Arx 1980), resemble yeasts isolated from the cigarette beetle, *Lasioderma serricorne* (Fabr.) and probably represent a new species (P. Dowd, personal communication). Larval dissections showed six, blue-gray, grape-like clusters (mycetomes) attached to a ring shaped structure between the crop and midgut (Fig. 4). Thin membranes loosely hold these mycetomes in place.

Upon emergence most larvae wander at least 1 cm from the oviposition site before attempting to enter the wood. Less than 20% of larvae (> 200, total observed) penetrated the substrate directly through the chorion. The greatest distance any larva moved from the oviposition to a penetration site was approximately 8 cm. Hickin (1981) noted that newly emerged *A. punctatum* larvae usually chew directly through the egg into wood, and therefore oviposition site selection by the adult female was of critical importance.

Larvae move by muscular undulations of the body that are directed from posterior to anterior. Upon locating a suitable site, first instars penetrate 2–3 mm at a 90° angle to the surface. Later instars formed feeding tunnels that followed the grain. Wood dissections and radiographs showed that larvae often fed within old galleries, changed positions through time, and widened the tunnel as their body size increased. Due to continued feeding, field collected wood was often reduced to powdery frass with little or no structural strength.

An attempt was made to promote development of *H. gibbicollis* on dog food

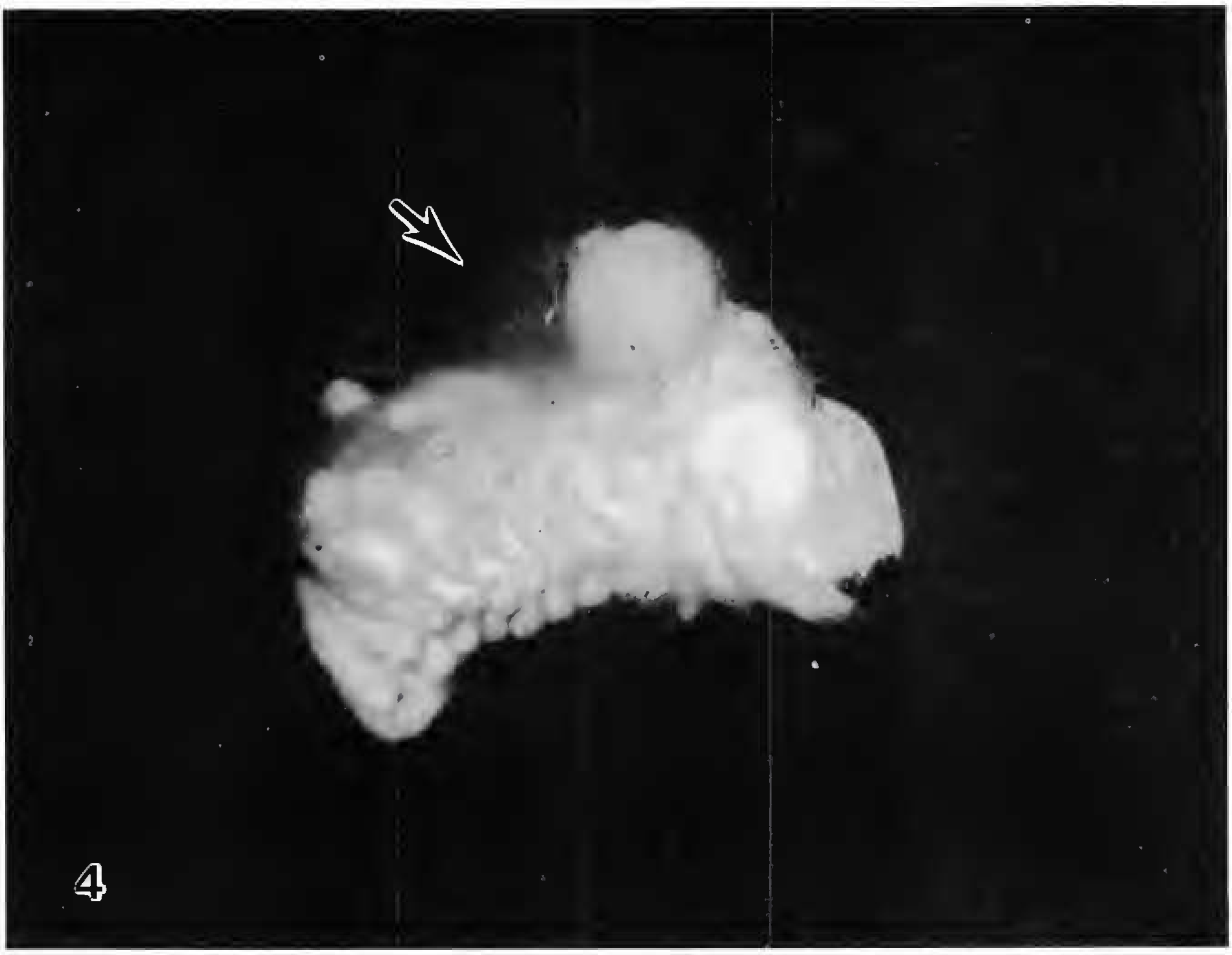

Figure 4. Mycetomes (containing symbiotic yeasts) located behind crop of *H. gibbicollis* larva.

(MiniChunks, Iams Company, Dayton, Ohio, 26% protein) and dog biscuits (Vita Bone, American Nutrition, Ogden, Utah, 20% protein), but none of the 30 larvae released on either food source survived. Other researchers have successfully reared *A. punctatum* on dog food and this dramatically decreased development time, often resulting in a 1 year life cycle (Baker & Bletchly 1966). However, high protein diets led to aberrant symbionts in the mycetomes (Berry 1976) or inconsistent responses to insecticidal treatments in subsequent generations of *A. punctatum* (Cross & Crabtree 1978).

Heartwood contains extractives that repel many insects (Miller 1987), and *H. gibbicollis* larvae were mainly found feeding within the sapwood portion of timbers. In certain instances larvae fed in heartwood, particularly if the sapwood had been depleted or if the heartwood had a moisture content of >17%. Two other wood-infesting anobiids, *A. punctatum* and *Euvrilletta peltata* (Harris), are found predominantly in sapwood as this is higher in carbohydrates and nitrogen (Becker 1942, Bletchly & Farmer 1959, Williams & Mauldin 1981). Upon emergence, most *H. gibbicollis* larvae penetrated into sapwood, but a high percentage still entered wood blocks through the heartwood. Of 65 larvae released, 46 (74.2%) were found in sapwood while 16 (25.8%) entered the blocks through heartwood. Three larvae died before penetrating the surface. Texture of wood at an entry site is probably the most important factor dictating this behavior.

*Larval Populations in Wood.*—Within individual wood blocks randomly cut from infested timbers, the number of *H. gibbicollis* larvae present was highly variable. Wood blocks radiographed during this research often showed extensive tunnelling by larvae, but no insects were found. On other occasions many larvae

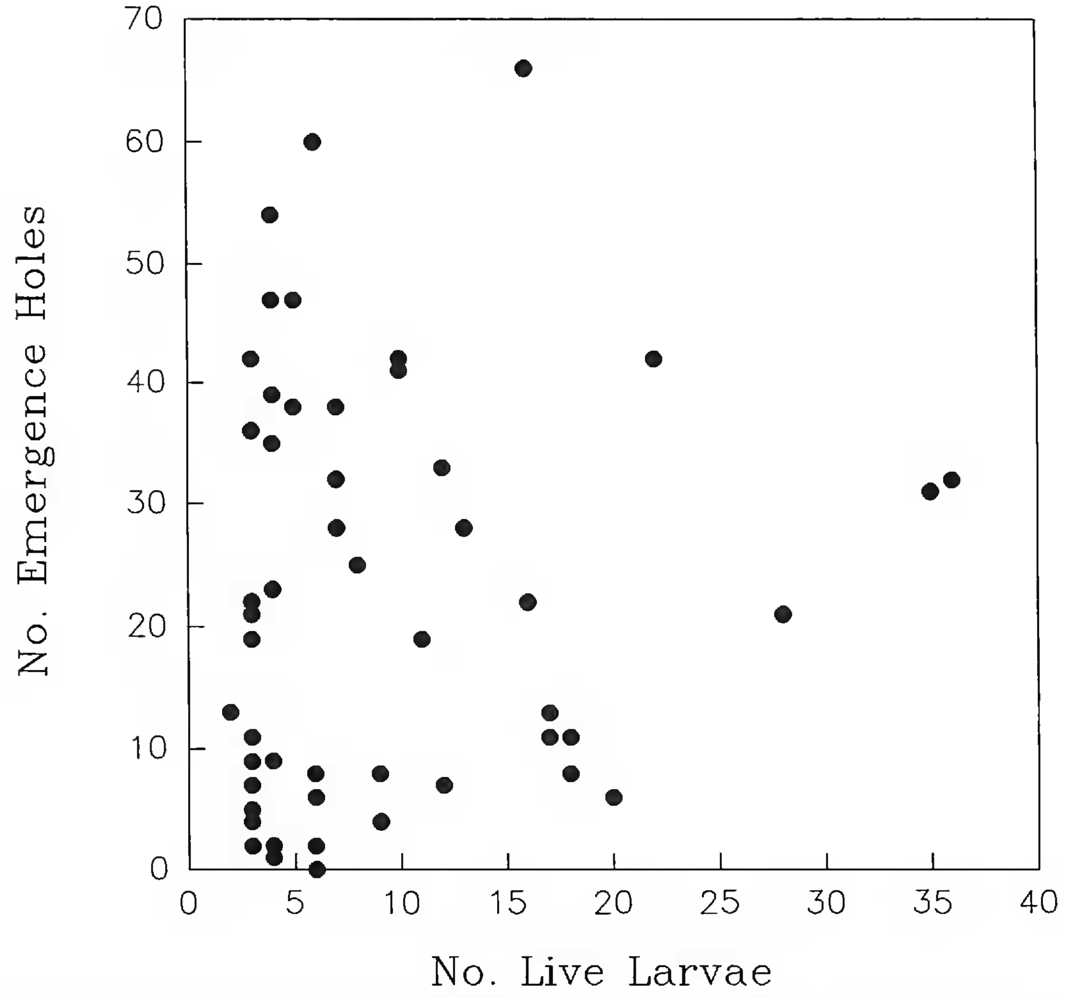

Figure 5. Number of *H. gibbicollis* adult exit holes compared to number of live larvae present in structural timbers.

were present; the maximum number found in one block was 55, which equal 631/929 $cm^2$ (per 1 $ft^2$). Williams (1973) found 72 *E. peltata* larvae/929 $cm^2$ in yellow poplar, *Liriodendron tulipifera* L., boards and 144 larvae/929 $cm^2$ in yellow poplar molding. These high numbers are relatively uncommon, but when found within structural timbers may quickly cause serious weakness. The average number of *H. gibbicollis* larvae found in a representative sample of 137 wood blocks (9 cm by 9 cm by 2 cm) was 7.3.

Although the literature is replete with statements that anobiids will only attack old, well seasoned wood (Linsley 1943, Chamberlin 1949, Ebeling 1975, Hickin 1981, Mampe 1982), this is not the case with *H. gibbicollis*. Replacement wood, attached to old infested timbers, in seven coastal homes harbored many anobiid larvae even though the wood had been in place for less than 10 years. Greater nutritional availability in wood harvested on shorter growth cycles may lead to serious anobiid problems in the future (Williams & Mauldin 1981). Bletchly (1957) demonstrated that *A. punctatum* was capable of infesting a wide variety of freshly cut hardwoods and softwoods. Williams & Mauldin (1974) reported that the anobiid *E. peltata* infested seasoned and unseasoned wood. Exit holes may not become apparent for 4–5 years and large scale infestations for 15–20 years because the holes are minute (< 2 mm) and often located in relatively inaccessible areas.

Most assessments of anobiid infestations made by the pest control industry are based on the number of adult exit holes on the wood surface. We found no correlation between the number of exit holes and larval counts within wood blocks (Fig. 5). Williams et al. (1979) supported this conclusion and further stated that the number of exit holes does not necessarily indicate that an infestation is active,

Table 1. Growth of *Hemicoelus gibbicollis* larvae within wood over a 2-year period.

| Larva no. | Initial length[a] | Terminal length | Size increase | Distance moved/month |
|---|---|---|---|---|
| 1.5-3 | 2.25 | 5.55 | 3.30 | 8.1 |
| 1.6-2 | 2.95 | 3.85 | 0.90 | 8.2 |
| 1.13-2 | 3.05 | 4.10 | 1.10 | 7.1 |
| 1.16-1 | 2.15 | 4.35 | 2.20 | 10.7 |
| 1.16-2 | 3.05 | 4.15 | 1.10 | 8.4 |
| 3.11-1 | 2.30 | 3.10 | 0.80 | 5.7 |
| 3.11-2 | 2.80 | 3.95 | 1.15 | 10.4 |
| 3.11-4 | 2.95 | 4.30 | 1.35 | 7.6 |
| 3.11-6 | 2.90 | 4.10 | 1.20 | 8.6 |
| 3.12-2 | 3.55 | 3.85 | 0.30 | 4.1 |
| 4.1-1 | 4.05 | 5.50 | 1.45 | 13.2 |
| 4.2-1 | 4.85 | 5.60 | 0.75 | 11.0 |
| 4.2-2 | 3.20 | 4.30 | 1.10 | 13.8 |
| 4.7-1 | 2.55 | 4.25 | 1.70 | 14.5 |
| 4.7-3 | 5.75 | 6.45 | 0.70 | 11.2 |
| 5.13-1 | 3.55 | 4.40 | 0.85 | 6.6 |
| 5.13-2 | 3.15 | 4.45 | 1.30 | 10.7 |
| 5.15-1 | 4.20 | 5.05 | 0.85 | 9.7 |
| 5.17-5 | 2.30 | 4.70 | 2.40 | 7.2 |
| 5.17-6 | 2.85 | 4.15 | 1.30 | 13.8 |

[a] Measurements in mm.

only the existence of larvae does. The best technique for determining presence of larvae is radiography.

Larvae appeared to be randomly distributed within most wood blocks. Occasionally, two or more were located within the same feeding tunnel, but most were positioned 0.5–1.0 cm apart. Generally, larvae moved 1 cm or less during a 30 day period. The maximum distance traveled by any immature was 4.4 cm over 30 days. During 24 months of radiographic observations the mean larval distance traveled was 0.95 ± 0.06 cm/month (mean ± SEM; $n = 220$, range = 0.07–4.44).

Lengths of 20 larvae were recorded at the beginning and end of a 2 year period (Table 1). These measurements were variable across the samples ($\bar{x} = 3.22 \pm 0.20$ mm). The average size increase over 24 months was 1.29 ± 0.15 mm and ranged between 0.30 and 3.30 mm. The average amount of growth each month was 0.06 mm (range = 0–0.45 mm). No correlation was noted between apparent size increase and amount of movement (Fig. 6). Activity was somewhat reduced in winter months, but larvae extracted during December, January, and February were capable of sustained movement within the frass-filled tunnels. It is unclear if a diapause is present in this species, but given year-round moderate climatic conditions in their native range, an arrested state of development is probably unnecessary.

The length of time anobiid larvae feed within wood is variable and depends primarily on available nutrition. Infested timbers collected in 1987 from a structure in western Washington continued to produce adult beetles in 1991. Radiographs showed that mature larvae were still present in late 1991. These larvae were >4 mm long and most, if not all, will probably emerge in 1992. Based on these data, the maximum time *H. gibbicollis* spends as a larva is 6 years. Williams

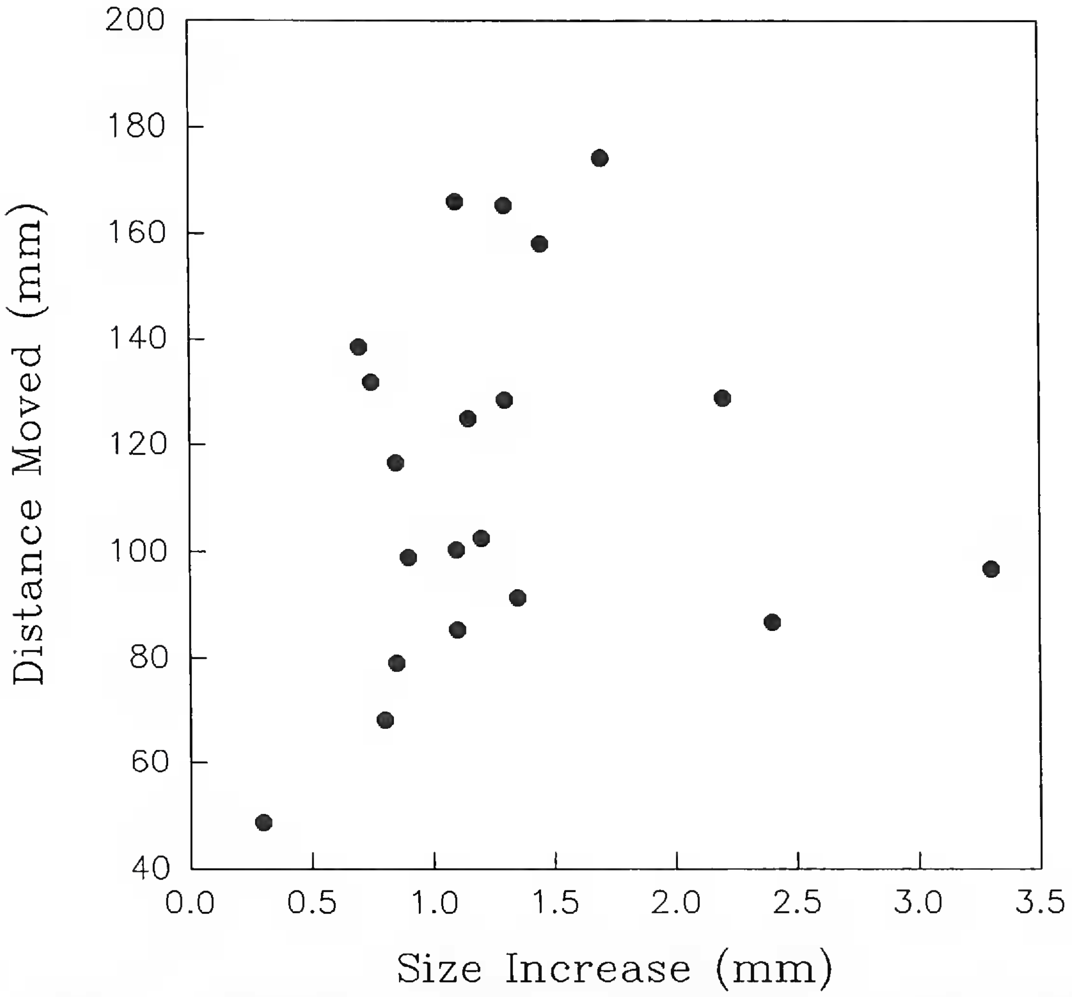

Figure 6. Growth of *H. gibbicollis* larvae related to movement within structural timbers.

& Mauldin (1981) reported the life cycle of *E. peltata* to be at least 2 years in favorable wood and possibly five in unfavorable wood. Baker & Bletchly (1966) and Hickin (1981) described the life cycle of *A. punctatum* as taking 3 years or more.

According to structural pest control operators in Washington and Oregon anobiid infestations often die out for unknown reasons, thus reducing or eliminating the need for insecticide applications. When wood nutrition becomes less available due to extensive feeding by larvae, emerging adults may choose more highly nutritious wood for oviposition (Bletchly & Farmer 1959, Bletchly & Taylor 1961). Also, anobiids are restricted from certain woods if the moisture content is above 20%, as this encourages development of *Penicillium* spp. that colonize on beetle eggs. If bark, which deters oviposition, is present on structural timbers, or if the nitrogen level has decreased substantially due to feeding by other organisms, oviposition may be significantly reduced (Robinson 1990).

When wood moisture levels were maintained at 11–12%, *H. gibbicollis* larvae did not survive longer than 18 months (Fig. 7). Smaller larvae died initially, and larger instars succumbed more slowly to the reduced wood moisture. Moore (1968) claimed that regulation of humidity (and wood moisture) alone would not be effective in controlling the initiation of an infestation by *E. peltata,* but Williams & Smythe (1978) stated that the advent of central heating and cooling in modern homes is probably the major factor in reducing anobiid infestations. Relative humidity, as it affects wood moisture, is the primary factor which influences anobiid infestations within structural timbers. Wood moisture levels between 14 and 17% are optimal for *H. gibbicollis* survival (Suomi 1992); levels above 19% resulted in development of decay fungi that effectively reduced numbers of both

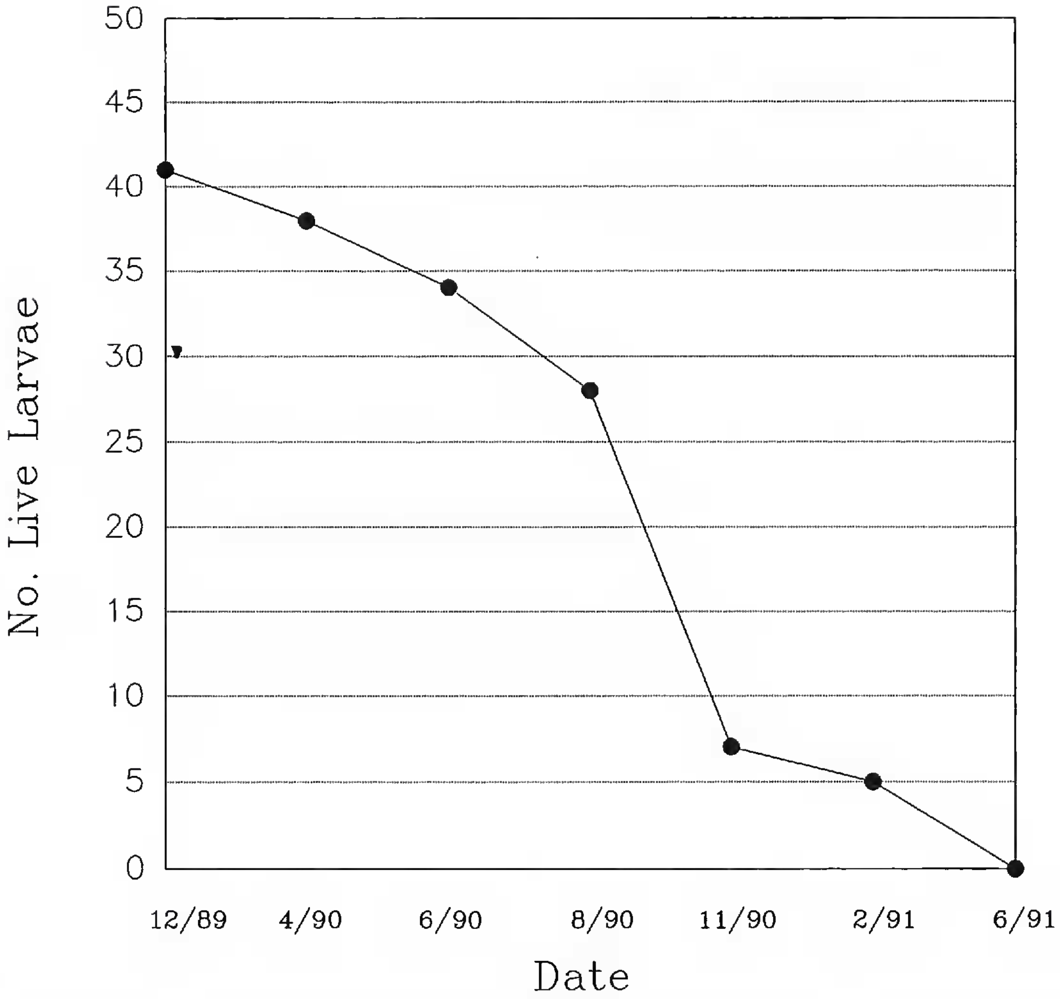

Figure 7. Survival of *H. gibbicollis* larvae in Douglas-fir blocks at 11–12% wood moisture.

eggs and larvae. Spiller (1948) also noted that *A. punctatum* survival was hindered at wood moisture levels above 20%.

In nature, *H. gibbicollis* larvae attack a wide variety of softwood and hardwood tree species (Table 2). The most accessible wood for a natural anobiid infestation are dead standing trees or stumps that remain undecayed for a minimum of 3 years, as most wood-infesting anobiids have a 3 year life cycle in nature (Berry 1976). Bletchly & Farmer (1959) demonstrated with *A. punctatum* that an increase in larval weight and survival was positively correlated with the nitrogen content of their host. Sapwood in trees is generally higher in amounts of soluble nitrogen and amino acids than heartwood (Merrill & Cowling 1966). Sapwood in contact with the ground is totally decayed in 3 years or less (Shigo 1968), so anobiids cannot complete their life cycles in this decomposing wood. The heartwood that remains is lower in nitrogen and higher in extractives which tend to repel anobiids (Parkin 1940).

*Pupa.*—During this research very few larvae were collected prior to pupation ($n = 4$, range = 5.3–6.1 mm, $\bar{x} = 5.7$ mm long). In two separate experiments, an attempt was made to promote pupation of *H. gibbicollis* by exposing infested wood blocks to different cooling regimes for varying lengths of time. Blocks held at 1.5° C and 14–15% wood moisture failed to produce any adult beetles during the normal emergence period. Radiographs taken 4 months and 1 year after the treatments revealed the presence of live larvae that were considerably smaller in size (up to 50% in certain cases) and showed little movement from their original positions. It is probable that these immatures were forced into a quiescent period with little or no feeding occurring, thus resulting in their reduced size.

Other infested wood blocks were placed at 2 month intervals in an unheated

Table 2. Known host tree species of *Hemicoelus gibbicollis*.

| Scientific Name[a] | Common Name | Reference |
|---|---|---|
| *Abies concolor* (Gordon & Glendinning) Lindley | grand fir | Knutson 1963 |
| *Abies grandis* (Douglas) Forbes | concolor fir | Knutson 1963 |
| *Acer macrophyllum* Pursh | bigleaf maple | Keen 1938 |
| *Alnus rubra* Bongard | red alder | Knutson 1963 |
| *Ceanothus thyrsiflorus* Eschscholz | buckthorn | Knutson 1963 |
| *Corylus cornuta* Marshall | hazelnut | Knutson 1963 |
| *Myrica californica* Chamisso | Pacific myrtle | Suomi 1992 |
| *Picea engelmannii* Parry | Engelmann spruce | Hatch 1946 |
| *Pinus monticola* Douglas | western white pine | Suomi 1992 |
| *Pinus* spp. | plywood | Suomi 1992 |
| *Prunus emarginata* (Douglas) Walpers | bittercherry | Furniss 1939 |
| *Pseudotsuga menziesii* (Mirbel) Franco | Douglas-fir | Doane et al. 1936 |
| *Quercus wislizensii* DeCondolle | oak | Knutson 1963 |
| *Salix lasiandra* Bentham | willow | Knutson 1963 |
| *Sequoia sempervirens* (D. Don) Endlicher | redwood | Keen 1938 |
| *Taxus brevifolia* Nuttall | Pacific yew | Knutson 1963 |
| *Thuja plicata* Don | western red cedar | Suomi 1992 |
| *Tsuga heterophylla* (Rafinesque) Sargent | western hemlock | Knutson 1963 |

[a] Plant names from Hitchcock & Cronquist (1973).

garage. Adults only emerged from blocks which had been moved out-of-doors 8 months prior to the normal adult emergence time in June, July, and August (Table 3). The first adult appeared during the second week of July and the last appeared in the third week of August.

French (1971) and Berry (1976) reported on the inability of *A. punctatum* to pupate under constant optimal temperatures. During this research, infested wood blocks maintained in indoor insectaries produced adult beetles every summer, but mainly from wood that had been collected the previous year. The greater the number of years that wood was kept indoors, the fewer adults emerged, even though many larvae were observed in radiographs. Berry (1976) stated that changes in moisture content or photoperiod do not induce pupation in *A. punctatum,* but

Table 3. Adult *Hemicoelus gibbicollis* emergence from wood blocks held out-of-doors, eastern Washington.

| No. months | No. larvae | No. emerged (%) |
|---|---|---|
| 2 | 11 | 0 (0) |
| 4 | 12 | 0 (0) |
| 6 | 12 | 0 (0) |
| 8 | 18 | 5 (28) |

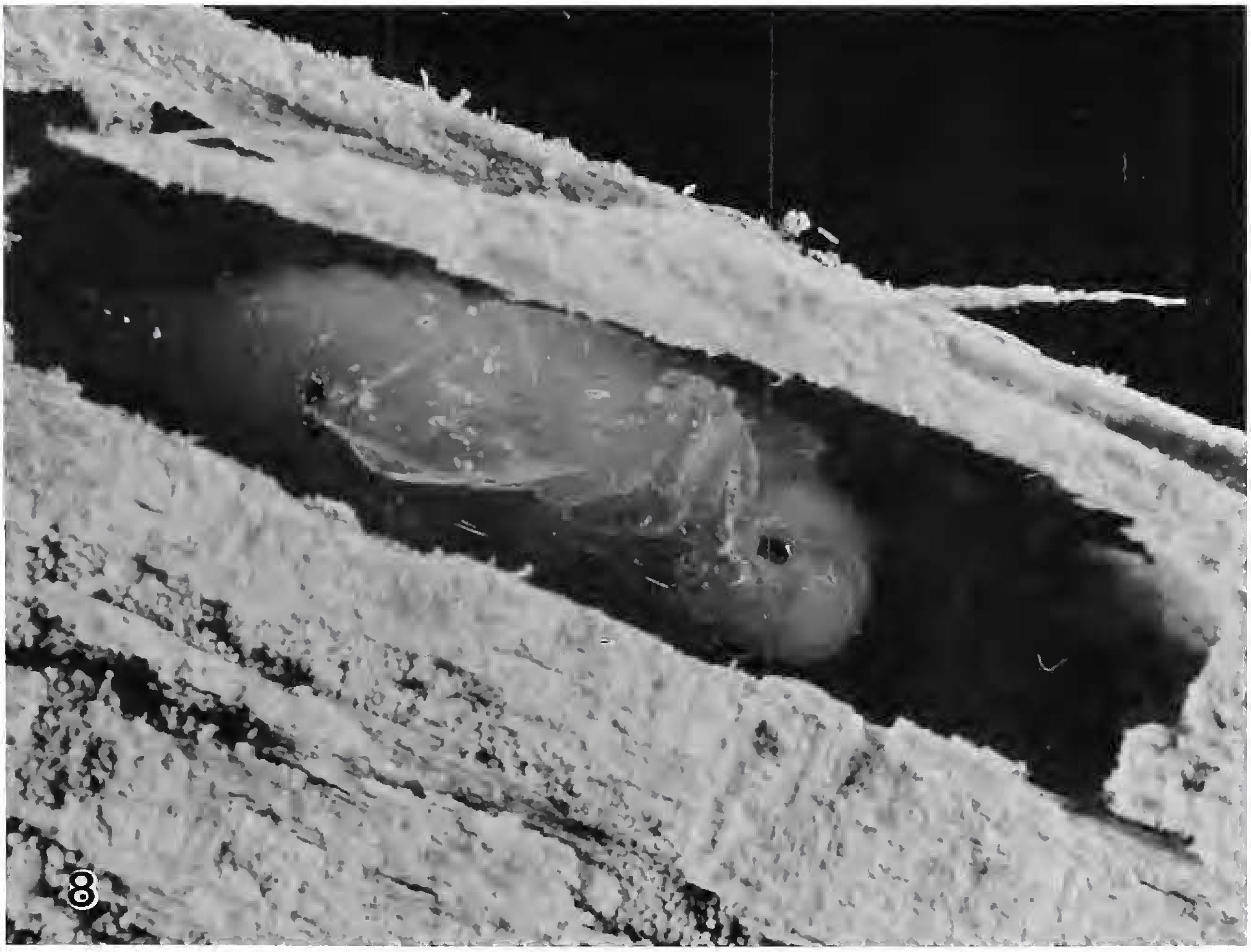

Figure 8. Pupa of *H. gibbicollis.*

rather, the pupal induction is dependent upon changes in temperature during a critical period in spring. Williams & Waldrop (1978) believe that emergence of *E. peltata* adults is synchronized by critical ambient temperature and relative humidity. With *H. gibbicollis,* it is likely that a combination of factors, including favorable temperatures, relative humidity (and thus, wood moisture), and larval size, induces pupation. To be effectively supplied with a laboratory population of these beetles, the best course is to collect infested wood and retain the material in an outdoor insectary which simulates environmental changes normally encountered by the insect.

*Hemicoelus gibbicollis* pupae were not easily observable by x-ray techniques. From images seen on the radiograph prior to pupation, larvae would cease moving and a decrease in length of 0.4–1.1 mm was noted. Six of 20 larvae observed eventually pupated and emerged as adults. No pupal cocoon was produced by this species. A change to the pupal form becomes imminent when a larva tunnels toward the outside surface of wood. Pupae examined were found in oval cells within 1–2 mm of the wood surface (Fig. 8). Four larvae were measured prior to pupation that ranged from 5.3 to 6.1 mm long and weighed between 8.1 and 11.0 mg. Bletchly (1953) reported average prepupal weights of 3.9 and 5.0 mg for male and female *A. punctatum,* respectively. In this same anobiid species, Berry (1976) observed successful pupation when larvae attained weights between 4 and 8 mg.

The change from larva to pupa required about 24 h and was observed on four occasions. Pupae are relatively active during this process and moved vigorously when exposed to light. Initially, pupae are white with red-brown eyes. Elytra sclerotize first, followed by the head and thorax, and finally, the abdomen. Pupae weighed between 5.2 and 7.4 mg and were approximately 4.5 mm long.

The minimum amount of time required to change from a mature larval form to a fully sclerotized adult beetle was 13 days; other pupal periods required 15, 19, and 22 days. French (1971) demonstrated that *A. punctatum* required 19–30 days to complete the pupal stage and Hickin (1975) reported the process lasted 2 to 3 weeks. In the Pacific Northwest, normal pupation for *H. gibbicollis* occurs from early May through mid-August.

## ACKNOWLEDGMENT

We thank the many structural pest control operators in Washington and Oregon who assisted us in locating anobiid infested structures. We would also like to thank Patrick Dowd, USDA-ARS, Peoria, Illinois, for assistance in dissections and identification of the symbionts.

## LITERATURE CITED

Baker, J. M. & J. D. Bletchly. 1966. Prepared media for rearing the common furniture beetle *Anobium punctatum* (DeG.) (Col. Anobiidae). J. Inst. Wood Sci., 17: 53–57.

Becker, G. 1942. Ökologische und physiologische Untersuchungen über die holzzerstörenden Larven von *Anobium punctatum* Deg. Z. Morph. Ökol. Tiere, 39: 98–151.

Berry, R. W. 1976. Laboratory rearing of *Anobium punctatum.* Mater. Org., 11: 171–182.

Berryman, A. A. & R. W. Stark. 1962. Radiography in forest entomology. Ann. Entomol. Soc. Am., 55: 456–466.

Bletchly, J. D. 1953. A note on the prepupal stage and the external sex characters of the pupae of *Anobium punctatum* Deg. (Coleoptera, Anobiidae). Bull. Entomol. Res. 43: 587–590.

Bletchly, J. D. 1957. The biological work of the Forest Products Research Laboratory, Princes Risborough. III. The work of the Entomology Section, with particular reference to the common furniture beetle, *Anobium punctatum* DeG. Proc. Linn. Soc. London, 168: 111–115.

Bletchly, J. D. 1961. The effect of x-radiation on some wood-boring insects. Ann. Appl. Biol., 49: 362–370.

Bletchly, J. D. & W. J. Baldwin. 1962. Use of x-rays in studies of wood-boring insects. Wood, 27: 485–488.

Bletchly, J. D. & R. H. Farmer. 1959. Some investigations into the susceptibility of Corsican and Scots pines and of European oak to attack by the common furniture beetle, *Anobium punctatum* DeGeer (Col., Anobiidae). J. Inst. Wood Sci., 3: 2–20.

Bletchly, J. D. & R. C. Fisher. 1957. Use of gamma radiation for the destruction of wood-boring insects. Nature, 179: 670.

Bletchly, J. D. & M. Taylor. 1961. Methods of testing preservatives against the common furniture beetles (*Anobium punctatum* DeG) and the house longhorn beetle (*Hylotrupes bajulus* L.). J. Inst. Wood Sci., 3: 4–11.

Böving, A. G. 1954. Mature larvae of the family Anobiidae. Det K. Dan. Vidensk. Selsk. Biol. Medd., 22: 1–298.

Canadian Insect Pest Report. 1988. Insect conditions. 66: 75.

Chamberlin, W. J. 1949. Insects affecting forest products and other materials. Oregon State College Coop. Assoc., Corvallis.

Cross, D. & R. Crabtree. 1978. Artificial medium for rearing *Anobium punctatum* Deg. J. Inst. Wood Sci., 8: 34–37.

Dennis, N. M. 1961. The effects of gamma-ray irradiation on certain species of stored-product insects. J. Econ. Entomol., 54: 211–213.

Doane, R. W., E. C. Van Dyke, W. J. Chamberlin & H. E. Burke. 1936. Forest insects. McGraw Hill, New York.

Ebeling, W. 1975. Urban entomology. Univ. California, Div. Agric. Sci., Berkeley.

Fisher, R. C. & H. S. Tasker. 1940. The detection of wood-boring insects by means of x-rays. J. Agric. Res., 14: 347–348.

French, J. R. J. 1971. The effect of temperature and humidity on the life cycle of the common furniture beetle, *Anobium punctatum* (DeGeer). J. Inst. Wood Sci., 5: 31–35.

Furniss, R. L. 1939. Insects attacking forest products and shade trees in Washington and Oregon in 1937. Proc. Entomol. Soc. Brit. Columbia, 35: 5–8.

Gams, W. & J. A. von Arx. 1980. Validation of *Symbiotaphrina* (imperfect yeasts). Persoonia, 10(4): 542–544.

Hatch, M. H. 1946. *Hadrobregmus gibbicolis* infesting woodwork. J. Econ. Entomol., 39: 274.

Hickin, N. E. 1974. Household insect pests. Associated Business Programmes, London.

Hickin, N. E. 1975. The insect factor in wood decay. Associated Business Programmes, London.

Hickin, N. E. 1981. The woodworm problem (3rd ed.). Hutchinson, London.

Hitchcock, C. L. & A. Cronquist. 1973. Flora of the Pacific Northwest. Univ. Wash. Press, Seattle.

Jurzitza, G. 1979. The fungi symbiotic with anobiid beetles. pp. 65–76. *In* Batra, L. R. (ed.). Insect–fungus symbiosis. Allanheld-Osmun, Montclair.

Keen, F. P. 1938. Insect enemies of western forests. USDA Misc. Publ. 273.

Kelsey, J. M. 1958. Symbiosis and *Anobium punctatum* De Geer. Proc. R. Entomol. Soc. Lond., A: 21–24.

Knutson, L. V. 1963. Revision of the genus *Hadrobregmus* of North America (Coleoptera: Anobiidae). Proc. Entomol. Soc. Wash., 65: 177–195.

Linscott, D. 1971. Susceptibility of imported and newly-seasoned home-grown hardwoods to *Anobium punctatum* (Deg.). J. Inst. Wood Sci., 5: 36–39.

Linsley, E. G. 1943. The recognition and control of deathwatch, powderpost, and false powderpost beetles. Pests, 11: 11–14.

Mampe, C. D. 1982. Wood-boring, book-boring, and related beetles. pp. 276–309. *In* Mallis, A. (ed.). Handbook of pest control (6th ed.). Franzak and Foster, Cleveland.

Merrill, W. & E. B. Cowling. 1966. Role of nitrogen in wood deterioration: amounts and distribution in tree stems. Can. J. Bot., 44: 1555–1580.

Miller, R. B. 1987. Structure of wood. pp. 2.2–2.5. *In* Davidson, M. and A. Freas (eds.). Wood handbook: wood as an engineering material. USDA For. Serv. Agric. Handb. 72.

Milner, M., M. R. Lee & R. Katz. 1950. Application of x-ray technique to the detection of internal insect infestation of grain. J. Econ. Entomol., 43: 933–935.

Moore, H. B. 1968. Development and longevity of *Xyletinus peltatus* under constant temperatures and humidities. Ann. Entomol. Soc. Am., 61: 1158–1164.

Pant, N. C. & G. Fraenkel. 1954. Studies on the symbiotic yeasts of two insect species, *Lasioderma serricorne* F. and *Stegobium paniceum* L. Biol. Bull., 107: 420–432.

Parkin, E. A. 1940. The digestive enzymes of some wood-boring beetle larvae. J. Exp. Biol., 17: 364–377.

Robinson, W. H. 1990. Wood-boring, book-boring, and related beetles. pp. 282–310. *In* Mallis, A. (ed.). Handbook of pest control (7th ed.). Franzak and Foster, Cleveland.

SAS Institute. 1985. SAS user's guide: statistics, version 5 ed. Cary, North Carolina.

Shigo, A. L. 1968. Discoloration and decay in hardwoods following inoculations with hymenomycetes. Phytopathology, 58: 1493–1498.

Spiller, D. 1948. Toxicity of boric acid to the common house borer *Anobium punctatum* DeGeer. N. Z. J. Sci. Technol. Sect. B, 30: 163–165.

Suomi, D. A. 1992. Biology and management of the structure-infesting beetle, *Hemicoelus gibbicollis* (LeConte) (Coleoptera: Anobiidae). Ph.D. Dissertation, Washington State University, Pullman.

Suomi, D. A. & R. D. Akre. 1993. Biological studies of *Hemicoelus gibbicollis* (LeConte) (Coleoptera: Anobiidae), a serious structural pest along the Pacific coast: adult and egg stages. Pan-Pacific Entomol. 69(2): 155–170.

Villani, M. G. & R. J. Wright. 1988. Use of radiography in behavioral studies of turfgrass-infesting scarab grub species (Coleoptera: Scarabaeidae). Bull. Entomol. Soc. Am., 34: 132–144.

Williams, L. H. 1973. Anobiid beetles should be controlled. Pest Control, 41(6): 18, 20, 22, 38, 40, 42, 44.

Williams, L. H. & J. K. Mauldin. 1974. Anobiid beetle, *Xyletinus peltatus* (Coleoptera: Anobiidae), oviposition on various woods. Can. Entomol., 106: 949–955.

Williams, L. H. & J. K. Mauldin. 1981. Survival and growth of the anobiid beetle, *Xyletinus peltatus* (Coleoptera: Anobiidae), on various woods. Can. Entomol., 113: 651–657.

Williams, L. H. & R. V. Smythe. 1978. Wood-destroying beetle treatment incidence in Arkansas and Georgia during 1962 and 1967 with estimated losses caused by beetles for 11 southern states during 1970. USDA For. Serv. Res. Pap. SO-143.

Williams, L. H. & J. D. Waldrop. 1978. *Xyletinus peltatus* seasonal flight, diel activity, and associated environmental influences. Ann. Entomol. Soc. Am., 71: 567–574.

Williams, L. H., H. M. Barnes & H. O. Yates, III. 1979. Beetle, (*Xyletinus peltatus*) and parasite exit hole densities and beetle larval populations in southern pine floor joists. Environ. Entomol., 8: 300–303.

*Received 15 April 1992, accepted 2 February 1993.*